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REVIEW

Mitigation Option of Greenhouse Gas Emissions from Livestock Manure Composting

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Abstract

Composting of livestock manure is a significant source of greenhouse gases such as nitrous oxide (N_2O), but the complexity of the N_2O generation pathway hinders efforts to develop effective countermeasures. In this paper, we present one mitigation option for N_2O emissions from composting. Nitrite (NO_2^-) has an important role in N_2O generation. It has been observed that significant N_2O emissions from composting are induced when NO_2^- is accumulated during nitrification. Accordingly, in our technique, nitrite-oxidizing bacteria (NOB), as nitrifying bacteria, are added in the middle of composting fermentation to prevent NO_2^- accumulation. Adding NOB prevents prolonged NO_2^- accumulation, which had resulted in low N_2O emissions. This technique is also cost-effective, because mature compost can be used as an NOB source. Mitigating N_2O emissions allows more nitrate nitrogen (NO_3^-), of high value as fertilizer, to be preserved in the compost product. Moreover, it was confirmed that this technique could be combined with that for NH_3 mitigation using chemical reagents. Before actual use, it is necessary to investigate the methods used to determine optimal timing to add NOB source and prevent N_2O from being generated from an NO_3^- reduction.

Discipline: Agricultural environment, animal industry
Additional key words: nitrification, nitrite-oxidizing bacteria, nitrous oxide

Introduction

Composting is a principal means of treating organic waste such as livestock manure. However, during the composting process, substantial amounts of harmful environmental gases are emitted, including greenhouse gases such as nitrous oxide (N_2O) (Czepiel et al. 1996, Fukumoto et al. 2003a, Osada et al. 2000, Sommer 2001). Accordingly, reducing the emission of harmful gases from the composting process has become increasingly important.

N_2O is a powerful greenhouse gas, with a global warming effect around 300-fold stronger per molecule than carbon dioxide (IPCC 2001). Moreover, N_2O also impacts on ozone layer depletion (Crutzen 1981). Agriculture is the largest source of anthropogenic N_2O emissions, of which livestock activity in particular makes a significant contribution (FAO 2006). Accordingly, it is important to develop a technique to reduce N_2O emissions from livestock activity, including composting of livestock manure. However, there are relatively few countermeasures to reduce N_2O emissions from composting compared to NH_3 emissions.

The authors have been trying to develop countermeasures to reduce N_2O emissions from composting of livestock manure. In this paper, we present the mitigation option and discuss issues concerning its actual usage.

N_2O generation in the composting process

N_2O is generated via both nitrification and denitrification processes as intermediate products or by-products during the composting process. The lack of nitrite/nitrate contained in fresh manure means the nitrification start is a prerequisite for N_2O generation from the composting process. Nitrification is performed by two kinds of bacteria, i.e.

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ammonia-oxidizing and nitrite-oxidizing (AOB and NOB). These bacteria cannot be active when exposed to high temperature and high free ammonia; their growth begins after the high-temperature period of composting fermentation.

During the composting process, nitrite (NO_2^-) is key to N_2O generation (He et al. 2001). Accordingly, there is potential to mitigate N_2O emissions by controlling NO_2^-. Based on this hypothesis, we conducted several composting experiments.

Mitigating N_2O emissions by adding nitrite-oxidizing bacteria

To mitigate N_2O emissions by controlling NO_2^-, we attempted the complementary addition of NOB of nitrifiers midway through the composting process. In our experiments, it was confirmed that the prolonged accumulation of NO_2^- tended to emerge during swine manure composting, underlining the suitability of the experiment to determine the effect of NOB addition on NO_2^- accumulation and N_2O emissions.

Our first study on the effect of NOB addition in swine manure composting was conducted using a laboratory-scale apparatus (Fukumoto et al. 2006). Continuous ventilation was conducted at a fixed rate (10 L/min) and the N_2O concentration in the exhaust air from the apparatus was continuously measured by an infrared photoacoustic detector (IPD, multigas monitor type 1312, Innova, Denmark). In this experiment, we used mature swine compost as the NOB source added after the thermophilic composting phase (Fig. 1), which contained around 10^6 NOB cells per gram.

Changes in the number of nitrifying bacteria (AOB and NOB) were shown in Figure 2. During the thermophilic composting phase, there were few nitrifying bacteria, but AOB subsequently began to increase. However, the growth of indigenous NOB was significantly delayed compared to AOB in the control. Conversely, the cell density of the NOB population remained high after adding the NOB source.

Changes in concentrations of inorganic nitrogen compounds were shown in Figure 3. After the AOB growth, NH_4^+ oxidization started, but because of NOB absence, NO_2^- oxidization stalled, resulting in NO_2^- accumulation in the control. Conversely, with NOB addition, NO_2^- was smoothly oxidized into NO_3^- and no prolonged NO_2^- accumulation was observed. Moreover, it emerged that artificially adding the NOB source could prevent prolonged NO_2^- accumulation during swine manure composting.

In this experiment, we added the mature swine compost at an additional rate of 10% (w/w), which rapidly led to complete nitrification. However, a similar result was also obtained in another experiment with a lower additional rate (2% w/w) of mature swine compost, which contained around 10^5 NOB cell per gram (Fukumoto et al. 2011). Blouin et al. (1990) showed that an NOB concentration of at least 10^5 cell/ml was required before the complete oxidation

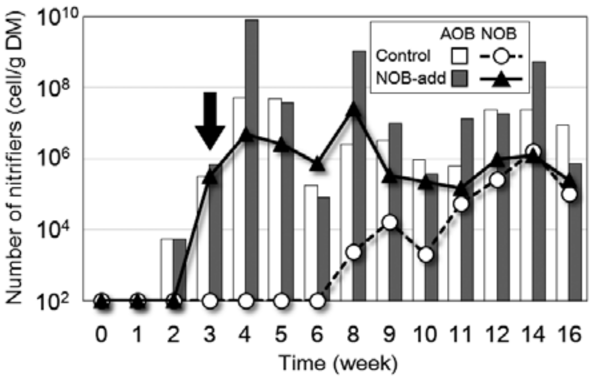

Fig. 2. Changes in the number of nitrifiers during swine manure composting.
Closed arrow indicates the addition of an NOB source of mature swine compost.

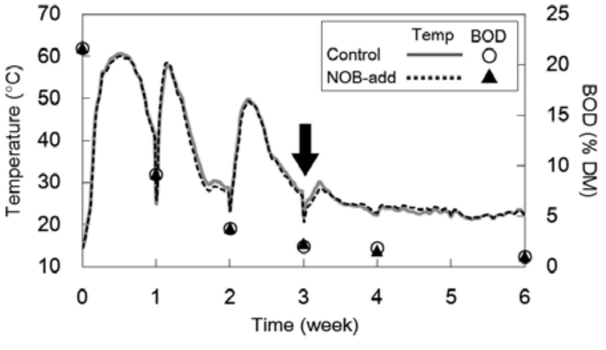

Fig. 1. Changes in the temperature of composting material and BOD concentration during swine manure composting.
Closed arrow indicates the addition of an NOB source of mature swine compost.

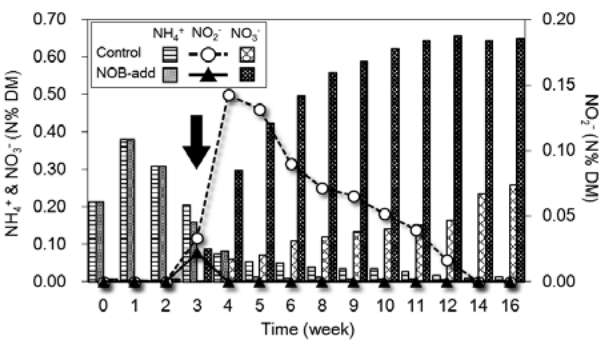

Fig. 3. Changes in the concentrations of inorganic nitrogen compounds during swine manure composting.
Closed arrow indicates the addition of an NOB source of mature swine compost.

of NO_2^- during the incubation of swine waste. However, because the population size of NOB can be grown even after the addition, we do not consider it crucial to fill the required cell number for complete nitrification when adding the mature compost. Adding mature compost during composting fermentation affects the workload, so further study is necessary to determine a suitable rate at which to add mature compost as the NOB source.

Emission patterns of N_2O were shown in Figure 4. N_2O emissions started after the thermophilic composting phase. In the control, N_2O emissions continued for an extended period, during which NO_2^- remained in the compost material. In contrast, N_2O emissions ceased within 1 week of adding the NOB source. Consequently, the total N_2O emissions during the composting experiment declined by 80% in the case of NOB addition compared to the control. Accordingly, we considered that a quantitative reduction effect of N_2O emissions from swine manure composting could be expected by adding the NOB source.

Effect of mitigating N_2O emissions on nitrogen preservation

Nitrogen loss during composting not only induces environmental problems but also reduces the compost value as a fertilizer. The key cause of nitrogen loss in composting is thought to be NH_3 emissions during the thermophilic phase. However, NH_3 volatilization and denitrification were reportedly of similar magnitude when composting swine manure (Petersen et al. 1998). In particular, as already shown in this paper, the quantity of nitrogen loss may vary significantly, with or without NO_2^- accumulation. Accordingly, we examined the nitrogen mass balance during swine manure composting with the treatment of adding NOB source (Fukumoto & Inubushi 2009).

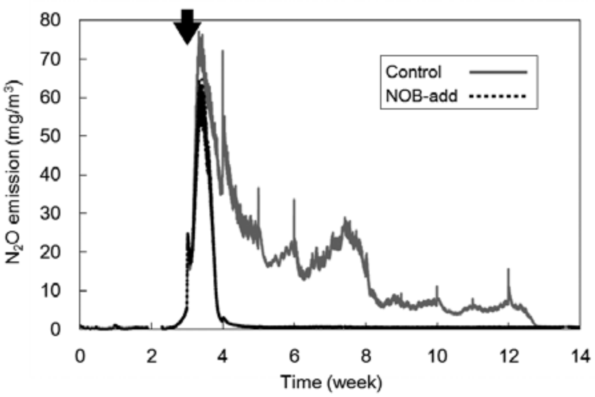

Fig. 4. Emission patterns of N_2O during swine manure composting.
Closed arrow indicates the addition of an NOB source of mature swine compost.

During the NO_2^- accumulation in swine manure composting, the increasing curve of NO_3^- was gentle, NO_3^- but increased quickly when the NOB source was added. Consequently, the NO_3^- content in the final product exceeded the control when adding the NOB source (Fig. 3). Moreover, NO_2^- accumulation induced not only N_2O emissions but also other nitrogenous emissions (Fig. 5). Accordingly, by avoiding NO_2^- accumulation, nitrogen loss during the maturation composting phase could be effectively reduced and NO_3^- nitrogen with high fertilizer value was preserved at a higher level in the final product.

Combination with struvite crystallization to reduce NH_3 emissions

There are several countermeasures to reduce NH_3 emissions from composting fermentation (Burrows 2006, Kuroda et al. 2004, Yasuda et al. 2009). Struvite crystallization is one of the effective countermeasures for NH_3 emissions. Struvite is crystallized magnesium ammonium phosphate (MAP), which is formed according to the following equation:

$$HPO_4^{2-} + NH_4^+ + Mg^{2+} + OH^- + 6H_2O \rightarrow MgNH_4PO_4{\cdot}6H_2O \text{ (Struvite)} + H_2O$$

Adding magnesium (Mg) and phosphate (PO_4) salts is an effective way to trigger struvite crystallization in the composting process (Jeong & Kim 2001). Combining with this technique allows nitrogen loss throughout the composting process to be mitigated. However, as had been reported, the reagent addition of struvite crystallization enhancement adversely impacts on microorganisms of composting fermentation (Jeong & Hwang 2005), while

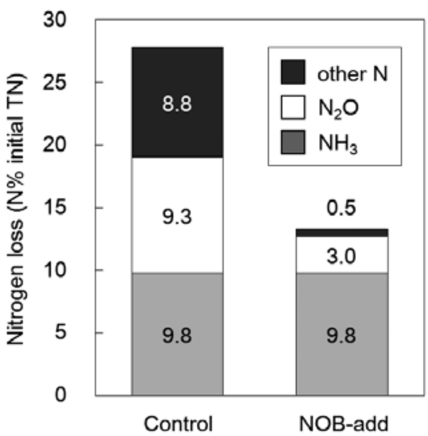

Fig. 5. Details of nitrogen losses during swine manure composting.
Nitrogen loss is indicated by the ratio of lost nitrogen based on total nitrogen (TN) in the initial compost material.

the technique of adding NOB to mitigate N_2O emissions depends on microbial activity. Accordingly, we conducted a composting experiment to investigate the potential for technical coexistence.

To quantify the combined effect of struvite crystallization and adding NOB source on the mitigation of nitrogenous emissions, swine manure composting experiments were conducted (Fukumoto et al. 2011). To enhance the struvite crystallization, $MgCl_2·6H_2O$ and H_3PO_4 were added at the start of composting, while mature swine compost was added as the NOB source after the thermophilic composting phase.

The NH_3 emissions declined when the reagents were added (Fig. 6). To confirm struvite crystallization, the amount of nitrogen fixed in struvite crystal was measured according to the procedure of Tanahashi et al. (2010). Consequently, the amount of nitrogen fixed in struvite crystal was shown to be higher when treating reagent addition (Fig. 7), which meant the struvite crystallization was considered to help reduce NH_3 emissions in this experiment.

Adding the NOB source reduced N_2O emissions, even after adding reagents for struvite crystallization (Fig. 6), while adding reagents did not affect the activity of nitrifying bacteria. Accordingly, it was thought that the technique of adding an NOB source could coexist with struvite crystallization.

Issues for practical usage

The effect of adding NOB source on the reduction in N_2O emission from the composting process was investigated and a quantitative reduction effect on N_2O emissions is expected using this technique (Fig. 8). However, due attention regarding the timing of NOB source addition is necessary. In our previous experiment, adding the NOB source during the thermophilic composting phase resulted in the extinction of NOB. Accordingly, this must be avoided and a method developed to determine the optimal time at which to add the NOB source during the composting process.

The effect of adding NOB source on mitigating N_2O emissions was confirmed in small-scale composting experiments. Accordingly, a larger scale experiment was necessary before actual use. As shown in this paper, this technique reduces N_2O emissions induced by NO_2^- accumulation during the nitrification process. However, N_2O generated from the NO_2^-/NO_3^- reduction process, i.e. denitrification cannot be mitigated by this technique. In particular, the increased scale of the compost pile causes the anaerobic portion inside the compost pile to expand (Fukumoto et al. 2003b). Accordingly, when this technique is applied in actual composting, it is important to minimize the N_2O derived from the denitrification process. For example, it may be effective to reduce the frequency of unnecessary pile turning after adding the NOB source. Based on the above issues, it is important to verify the effect of this technique in actual-scale composting.

Conclusion

During the composting process, prolonged NO_2^- accumulation induces significant N_2O emissions. The accumulation is caused by the delayed growth of indigenous NOB compared to AOB. Adding the NOB source (mature compost) in the middle of the composting process could prevent prolonged NO_2^- accumulation, which reduced N_2O emissions. This technique produces valuable compost with high nitrogen content and is expected to preserve greater amounts of nitrogen, alongside measures to reduce NH_3

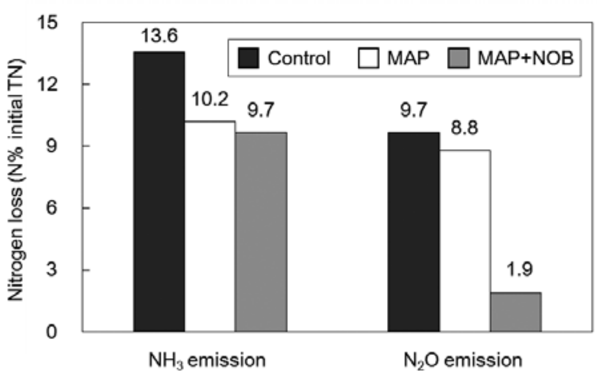

Fig. 6. Nitrogen losses by NH_3 and N_2O emissions during swine manure composting.
Nitrogen loss is indicated by the ratio of lost nitrogen based on total nitrogen (TN) in the initial compost material.

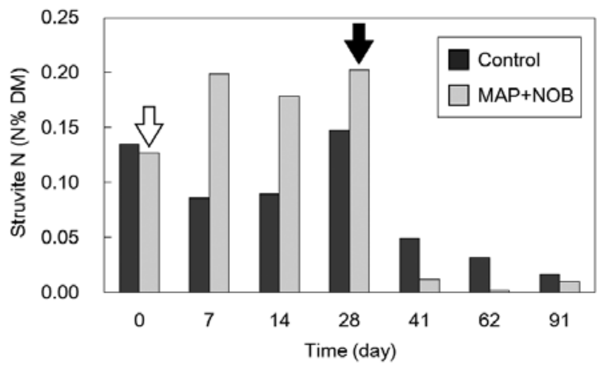

Fig. 7. Changes in the concentrations of nitrogen fixed in struvite crystal during swine manure composting.
Open arrow indicates the addition of reagents for struvite crystallization. Closed arrow indicates the addition of an NOB source of mature swine compost.

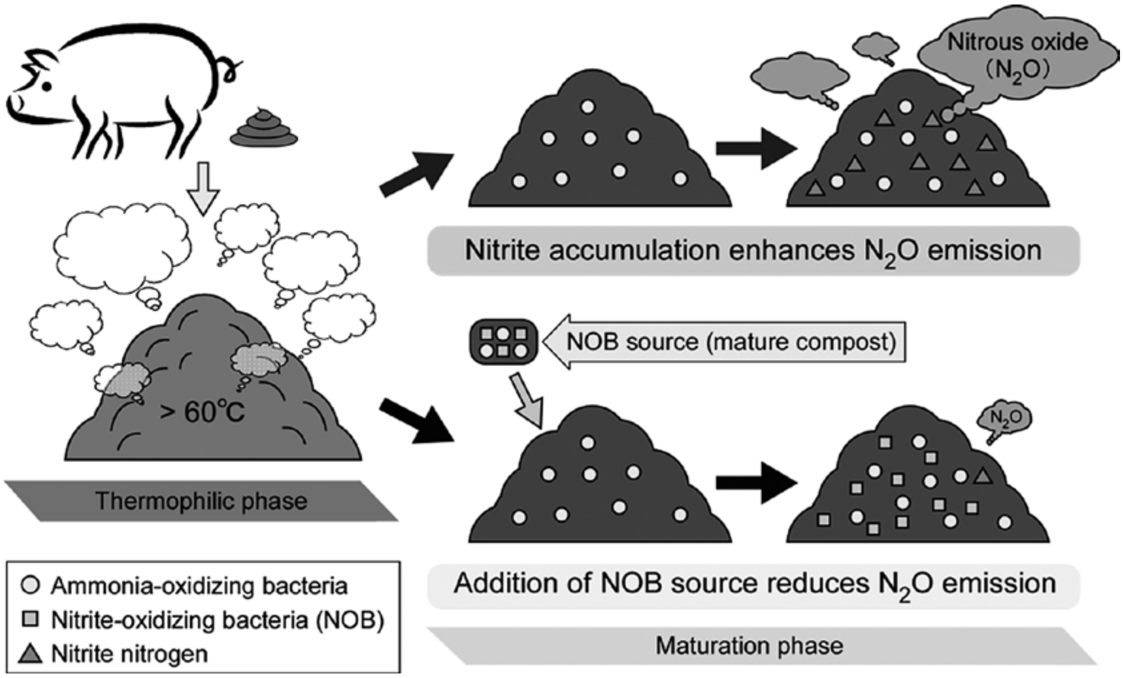

Fig. 8. Schematic of the bioremediational technique of mitigating N_2O emissions during the composting process.

emissions. To apply this technique to actual-scale composting, it is necessary to investigate methods to determine suitable times at which to add the NOB source and prevent N_2O from being generated from denitrification.

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